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DEVELOPMENT OF EQUIPMENT FOR EXPLOSIVE DRILLING

AAI Corporation

PREPARED FOR
Army Mobility Equipment Research and Development Command

June 1976

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ENGINEERING REPORT ER-8724

DEVELOPMENT OF EQUIPMENT FOR EXPLOSIVE DRILLING

FINAL REPORT
by.

W. L. BLACK

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Prepared by
AAI CORPORATION
COCKEYSVILLE, MD. 21030

for

U.S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT COMMAND

LABORATORY 6000
Fort Belvoir, Virginia 22060

CONTRACT NO. DAAG53-76-C-0033

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SUMMARY

A need exists in the Army, and in the construction industry as well, for an efficient, highly mobile, rapid means for drilling large diameter holes in hard rock. The Army's drilling requirements are more restrictive than might be tolerated in the construction industry, but the characteristics of equipment that will satisfy Army requirements should, nonetheless, provide a broad drilling capability that will have universal appeal as a construction tool. The Army's requirements can be summarized as follows:

1. Worldwide deployment is necessary; therefore, the equipment must be capable of operation in any type of soil or rock, under all types of climatic conditions.

2. The equipment must be of modest size and weight to be compatible with critical logistic requirements.

3. The capability for drilling holes up to 20 to 24-inch diameter in hard rock is necessary for special purpose emplacements.

4. The equipment must have a rapid emplacement capability both in hole drilling and emplacement set-up time.

Large quantities of energy are required to drill holes in hard rock. Commercial equipment is available in integrated, mobile units that is capable of drilling holes up to about 8 inches in diameter in this media, but the energy requirements are so great in holes larger than this that multi-unit equipment is needed that is heavy, expensive, and from the Army's viewpoint, logistically unacceptable. The chemical energy in explosives is one of the most efficient sources of potential energy available, and if an effective means can be found to utilize this energy to dislodge and break up the rock in the bottom of a borehole into particles that can be flushed to the surface, then explosive drilling can become a practical and attractive drilling process. Concepts for utilizing explosives in an effective manner in a drilling process were conceived, and research has been conducted that provides positive indications that explosive drilling can be an efficient process. This work provided an insight into the nature of the equipment that could be employed. One of the important products of this research was the development of a unique oil-plastic, multi-jet, shaped charge capsule. This serves as the drilling tool in this explosive drilling concept.

Based upon the results of this research, this program was planned and conducted to advance the development of an explosive capsule. Also, equipment is required that will feed these capsules into the borehole in a safe, controlled manner. This need has been satisfied by including in

the program the development of an automatic feeder that was adapted to a small commercial drilling unit to create a lightweight, mobile, explosive drill rig. Safety was a prime consideration in the designs for both the capsule and the feeder, and systems were designed and tested that provide the necessary safety provisions. Economy in manufacture for the explosive capsules is a very important consideration. This matter received considerable attention, and producible designs were developed for the capsule parts. Tooling was also developed to fabricate some of the parts to check the effectiveness of proposed production methods. Explosive loading of the capsules was also investigated, and success was achieved in modifying the capsule so that loading can be accomplished by a standard production process. Tests of the feeder and capsule were conducted to check performance. A check of safety provivions was an important part of these tests.

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A development program was conducted to provide special equipment for use in a planned rapid drilling, lightweight, high capacity, explosive drilling system. Development services were provided for a unique multi-jet, all plastic, shaped charge capsule used as the drilling tool, and an automatic feeder mechanism to feed the capsules to the borehole. This feeder equipment was adapted to a small commercial drilling unit to create an explosive drilling capability. Safety, capsule producibility, and explosive loading of the capsule were prime considerations during design and development.

FOREWORD

A development program was conducted by the AAI Corporation, Cockeysville, Maryland for Laboratory 6000, U. S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia. The services were performed under Contract DAAG53-76-C-0033, DA Project No. 1G762708AH67X. The program was concerned with the development of an automated feeder system for controlled, rapid feeding of explosive capsules in an explosive drilling concept currently under development. Research on the explosive capsule to add safety features, investigate methods of fabrication, and develop a method of explosive loading was also included in the program.

The program was performed during the period from October 1975 through June 1976 under the direction of James M. Dillon of Laboratory 6000, Fort Belvoir, Virginia. The project was managed at the AAI Corporation by W. L. Black under the supervision of H. C. Strickland, Department Manager. The principal designer was Jacob Sofinowski, III.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

A program was conducted to develop several items of equipment that are needed to convert an explosive drilling concept from its current research status to a developmental status. Part of this development effort was allocated to an automated capsule feeder that was installed on a commercial drill rig and provides the means for feeding a supply of explosive capsules into the borehole at controlled, rapid rates. A parallel effort was concerned with the development of an explosive capsule that will be safe to handle and use, and can be fabricated at a reasonable cost by conventional mass production methods. The production studies included the development of a satisfactory method for explosive loading the capsules.

This development program was preceeded by two research programs that examined basic concepts for explosive drilling. The objective of this research was to determine if means could be found to effectively use the large quantities of chemical energy in explosives to drill large diameter holes through difficult rock. Explosives are a highly concentrated source of potential energy, and if this energy can be employed efficiently to dislodge and break up in-situ materials into small particles or spoils that can be brought to the surface, their use to achieve an effective, lightweight drilling process can be realized. This research work produced positive indications that explosive drilling could be developed into an efficient process, and provided an insight as to the nature of the equipment that could be employed. One important product of the research was a unique all-plastic multi-jet, shaped charge capsule. A small 4-inch diameter capsule containing 160 grams of explosive was evolved that is capable of drilling a 14-inch diameter hole in quality limestones at the rate of 0.70 to 1.00 inch per explosion. The capsule produces seven jets of explosive energy that radiate in a pattern that concentrates a major portion of the energy on the bottom face of the borehole. A similar capsule, 5-inches in diameter, containing 265 grams of explosive, drilled a 20-inch diameter hole in good limestone. The significance of the shaped charge idea is that it directs a considerable portion of the explosive energy and concentrates it on the face of the rock. The above performances were obtained in an air filled hole. Details of this research effort is reported in references (1), (2), and (3).

The Army and the construction industry in general has the need for an efficient, rapid means of drilling large diameter holes in hard rock. Single mobile drilling units weighing up to 100,000 pounds are available that can drill holes up to 8 inches in diameter through solid rock, but the conventional equipment required to drill holes in the 8- to 24-inch diameter range become very large multiple unit arrangements.

The equipment envisioned for an explosive drilling rig with a 24-inch diameter drilling capability contrasts sharply with conventional equipment requirements. The equipment is envisioned as being transported on two $2\frac{1}{2}$-ton trucks. One truck would be employed as the carrier and mount for the drill rig, the compressor, and some of the auxiliary equipment. A second $2\frac{1}{2}$-ton truck would be used as a carrier for supplies and equipment such as the explosive capsules, drill rod, and casing. Equipment of these proportions is economical, readily available, highly mobile, and air transportable.

The Army's drilling requirements are more restrictive than might be tolerated by the construction industry. They can be briefly summarized as follows:

1. Worldwide deployment is necessary; therefore, the equipment must be capable of operating in any type of soil or rock, under all types of climatic conditions.

2. The equipment must be of modest size and weight to be compatible with critical logistic requirements.

3. The capability for drilling holes up to 20- to 24-inch diameter in hard rock is necessary for special purpose emplacements

4. The equipment must have a rapid emplacement capability both in hole drilling and emplacement set-up time.

The drilling tool in this explosive drilling concept is the explosive capsule. To achieve a safe, rapid drilling capability, a means must be provided for introducing the capsules into the borehole at a controlled, rapid rate. This operation must respond automatically to the control exercised by a driller stationed at a remote safe distance from the operation. To satisfy this requirement, an automated feeder was conceived, designed, fabricated, and installed on a selected commercial drilling apparatus. This provides the basic item of equipment in the explosive drilling system. One of the principal tasks on this program was the development of this capsule feeder equipment.

The basic design for the multi-jet, shaped charge explosive capsule was conceived and proven on the prior research programs. Several refinements were required to convert this concept to a capsule that could be loaded, handled, and used in the feeder in a safe, convenient manner. This program provided the design and development work required to achieve an operational capsule. This work included production engineering considerations, for the ability to manufacture the capsules at a reasonable cost is very important. Explosive loading of the capsule by a production process is also necessary. Techniques were developed for loading the capsule by an established production loading process. Details of this development activity are presented in the following portions of this report.

INVESTIGATIONS

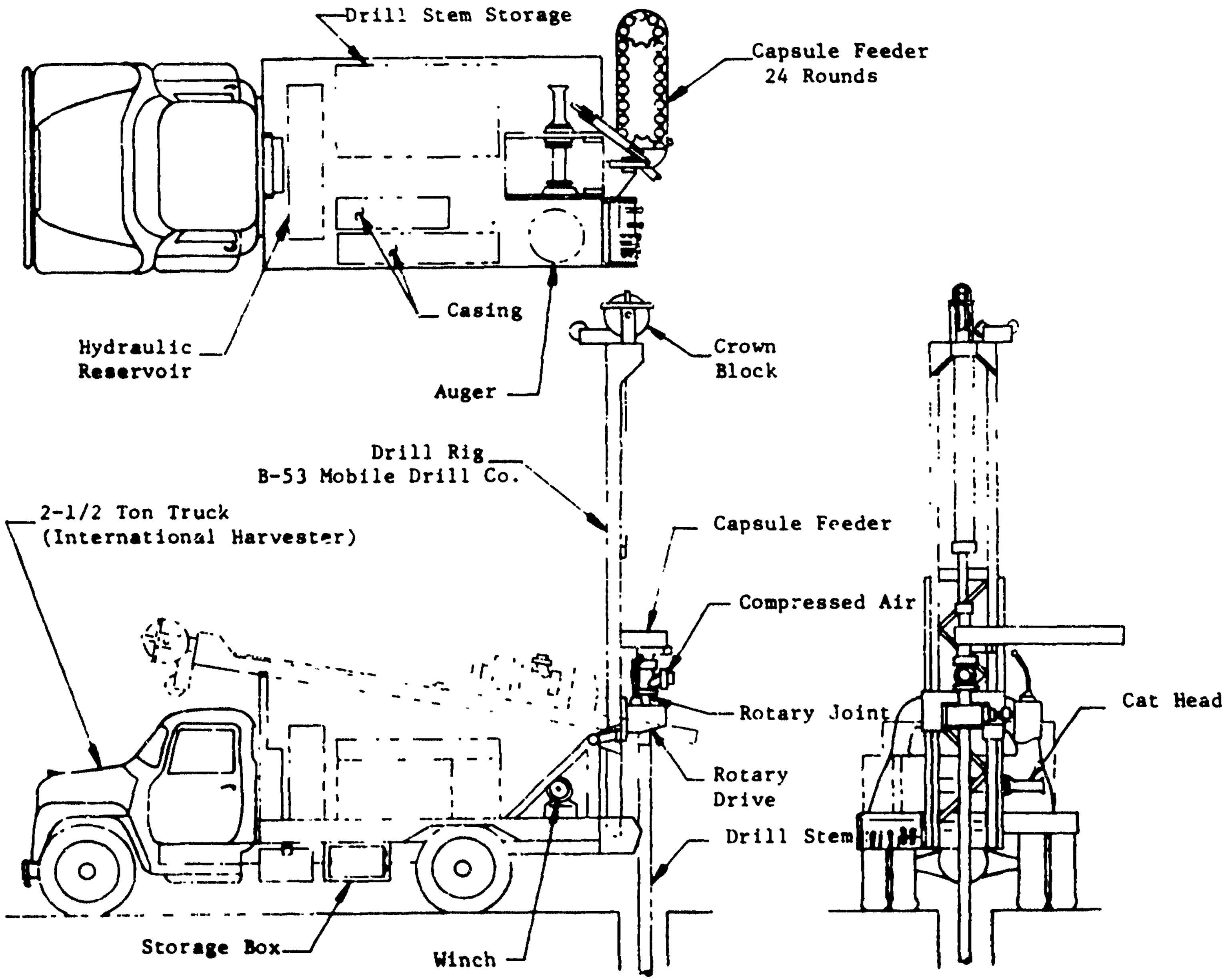
A. Review of Concepts.

For the envisioned explosive drilling system, the basic item of equipment in the system will be the drill rig. This rig will consist of light duty commercial drilling equipment modified to accommodate the equipment required to convert it to an explosive drilling capability. During the research programs, the concept shown in Figure 1 was projected as a probable design for this equipment. The photograph shown in Figure 2 is a view of the drilling equipment that evolved from this program. The feeder is installed, but it is less the compressor and other auxillary equipment that will eventually be added.

The equipment as it is currently composed consists of an International 2½-ton truck chassis with a Model B-53 drill, furnished by the Mobile Drill Company, installed. The drill is driven through a power take-off arrangement by the truck motor. This equipment was recommended by this contractor, but acquisition was accomplished by the Government and then furnished as a GFE item for installation of the capsule feeder.

The mode of operation is the following: The commercial drilling equipment will be used in a conventional manner to start the hole if the site is covered with material that can be drilled with an auger. Several lengths of commercial hollow-stem auger will be carried to accomplish this operation. As long as material can be removed from the borehole by the auger, this mode of operation will be continued, for this is the most efficient of all drilling techniques when conditions are favorable for this type of operation.

When rock is reached, the operation will be converted to explosive drilling. Without the benefit of experimental experience it is not clear what the best procedure will be, but the most optimistic projection is that explosive drilling can commence by merely starting the compressors and continue drilling by feeding explosive capsules at the desired rate with the capsule feeder. It is not known at this time whether the compressed air can force the spoils up along the flights of the auger. If this proves unworkable, the auger must be pulled and replaced with a drill stem designed solely for explosive drilling. The B-53 drilling equipment is capable of removing and adding drill stem or auger in 20-foot lengths.



General Arrangement - Explosive Drill Rig

Figure 1

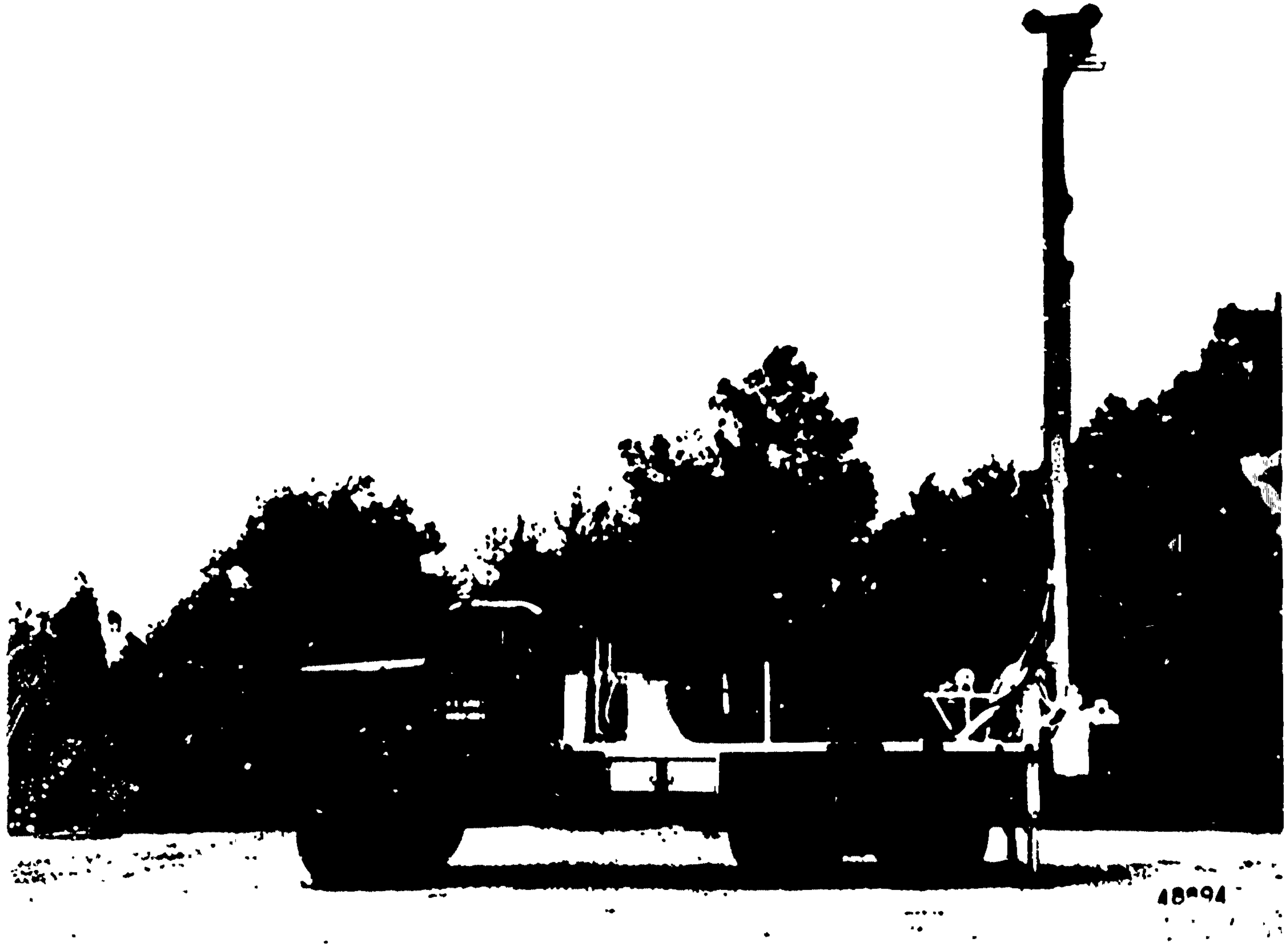


Figure 2. Configuration Of Current Explosive

B. Capsule Feeder Provisions

The capsule feeder assembly is attached to the B-53 drill rig as shown in Figure 3. The feeder consists of a tray that supports 24 cylindrical cups that are linked together to form an assembly that resembles an endless chain (see Figure 4). This chain is attached to two sprockets, one at the outboard or right end looking forward and the other at the inboard or left end. The left-end sprocket is driven, the right-end sprocket serves as an idler. Capsules are installed in the cups, one capsule to a cup. The driven sprocket is controlled by a pneumatically powered indexing mechanism. Every time the drive indexes, it moves the chain assembly 1/24 of a full revolution around the tray.

The tray can be located in three positions. The middle position is the operating position (see Figure 5). In this position an opening in the tray lines up with the drill stem, and when a capsule is moved over this opening by a stroke of the indexing mechanism, compressed air will force the capsule down through the cup into the drill stem and through the stem until it exits at the bottom of the borehole. The right-most position, looking forward, will locate the tray so that the lines from the cat head can be used to haul or install sections of drill stem or auger. The left-most tray position is its travelling location. It will rest entirely within the width o. the truck in this position.

The tray is equipped with sides and an assortment of guides to control the travel of the cups as they orbit around the tray. The capsules are installed by opening two flaps which are retained by pairs of quick-acting cam locks, and dropping a capsule in each cup. The cup over the drill stem cannot be filled; therefore, 23 capsules constitute a complete load. The flaps are closed and locked after insertion of the capsules. This prevents them from being thrown from their cups by shock and vibration during the drilling operations.

A tube assembly extends from the bottom opening in the tray down through the rotary drive of the commercial drill equipment. A rotary seal is provided in the tube assembly to prevent leakage of compressed air and permit operation of the rotary drive. Also an inlet port is provided for connecting the air supply used for spoils removal.

The feeder operates on air tapped from the receiver on the air brake system of the truck. Later, when the spoils removal compressors are added, operation could be accomplished from this supply also. The system has been designed to function an air pressure at 40 psig. The control system operates on 12 volts DC supplied by the truck electrical system.

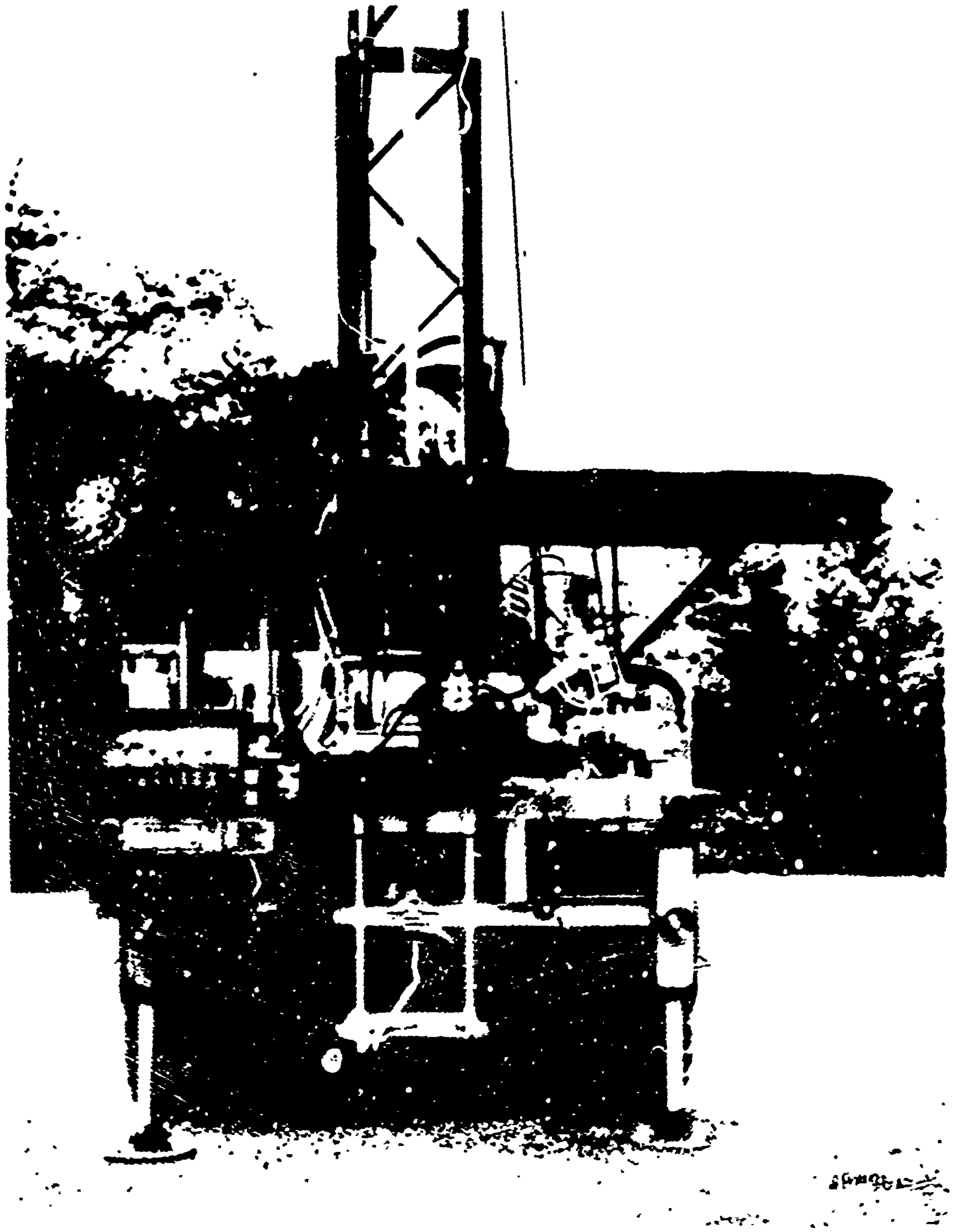


Figure 3. Capsule Feeder Mounted on Drill Rig

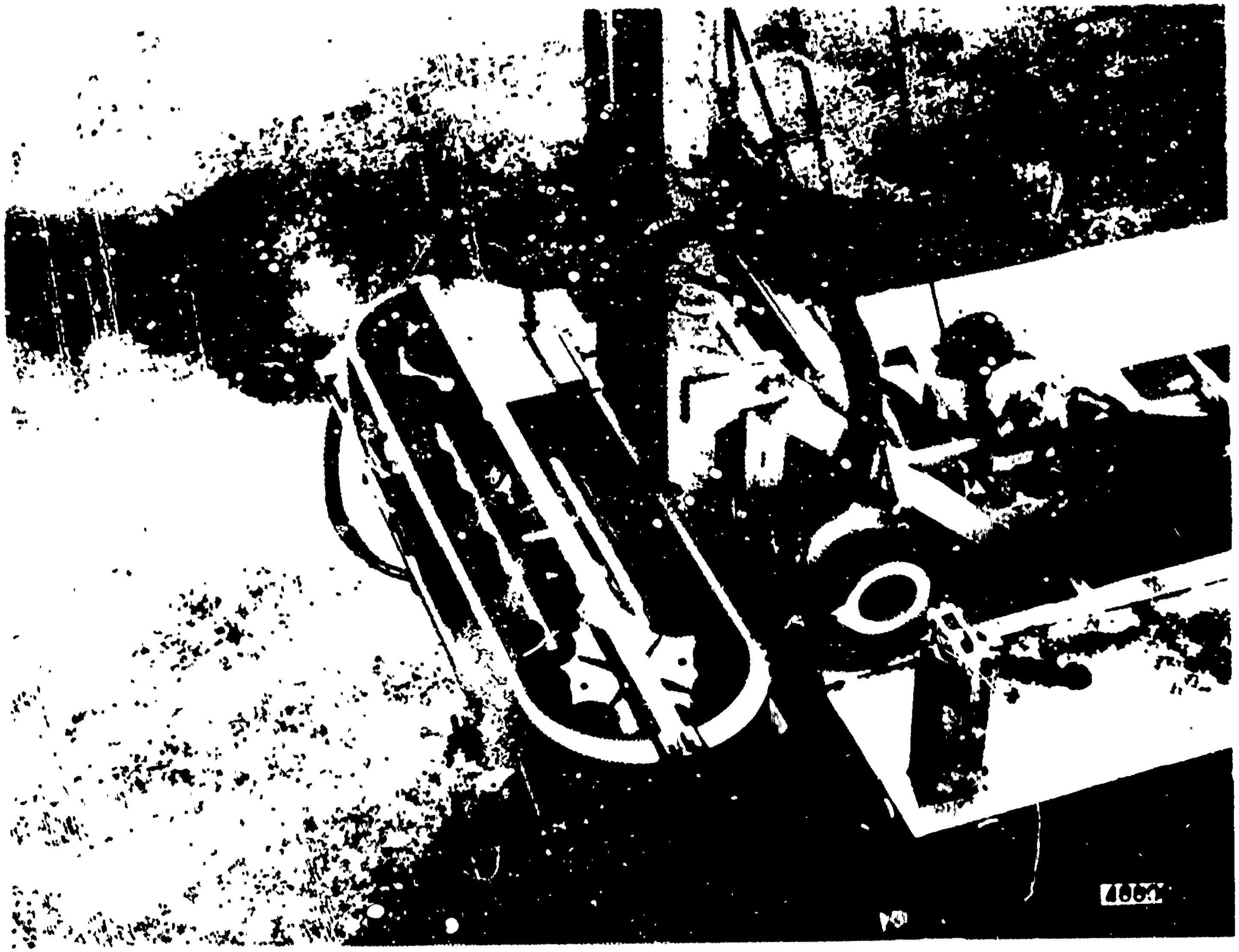


Figure 4. View Of Feeder Tray And Cups

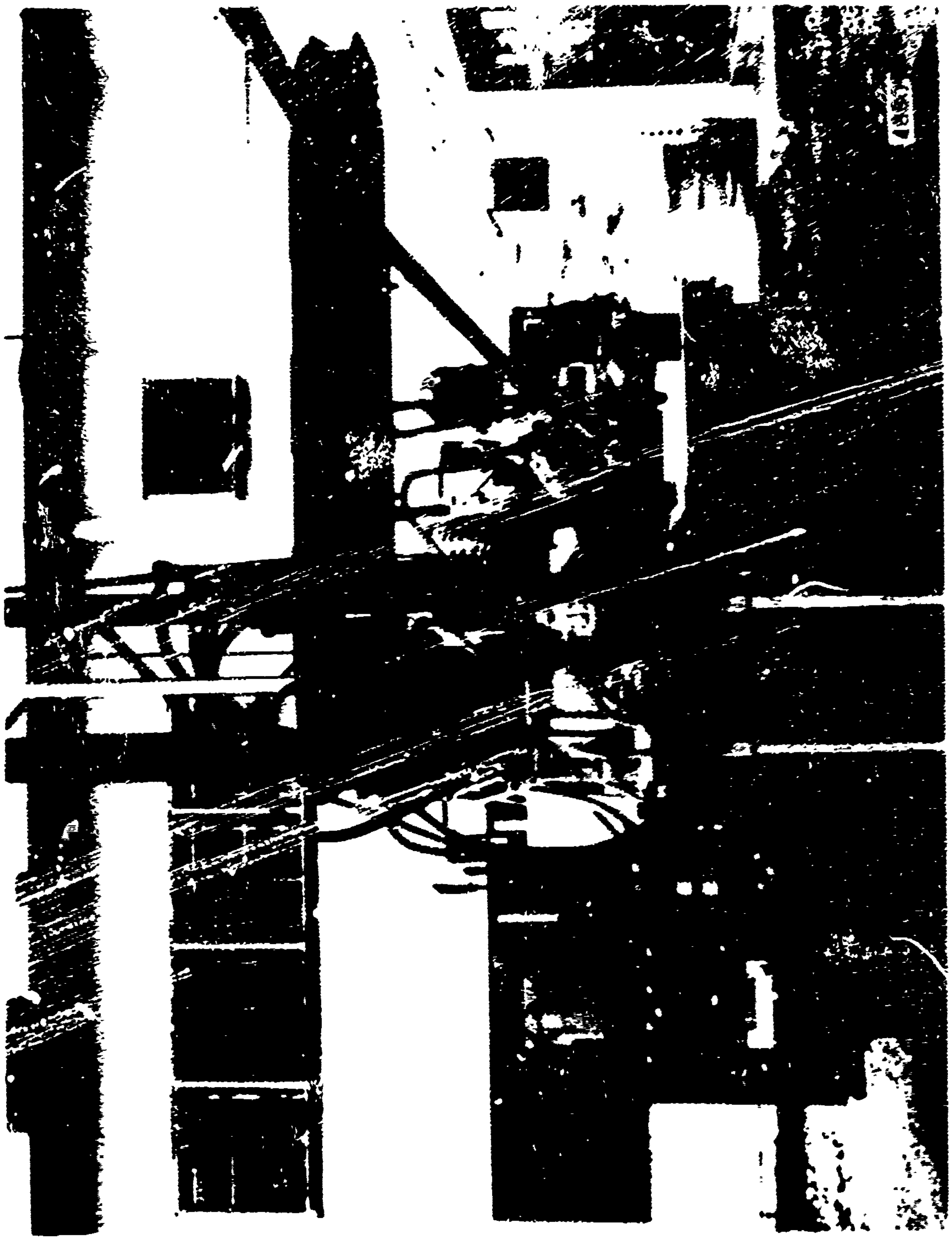


Figure 5. View Of Feeder In Operating Position

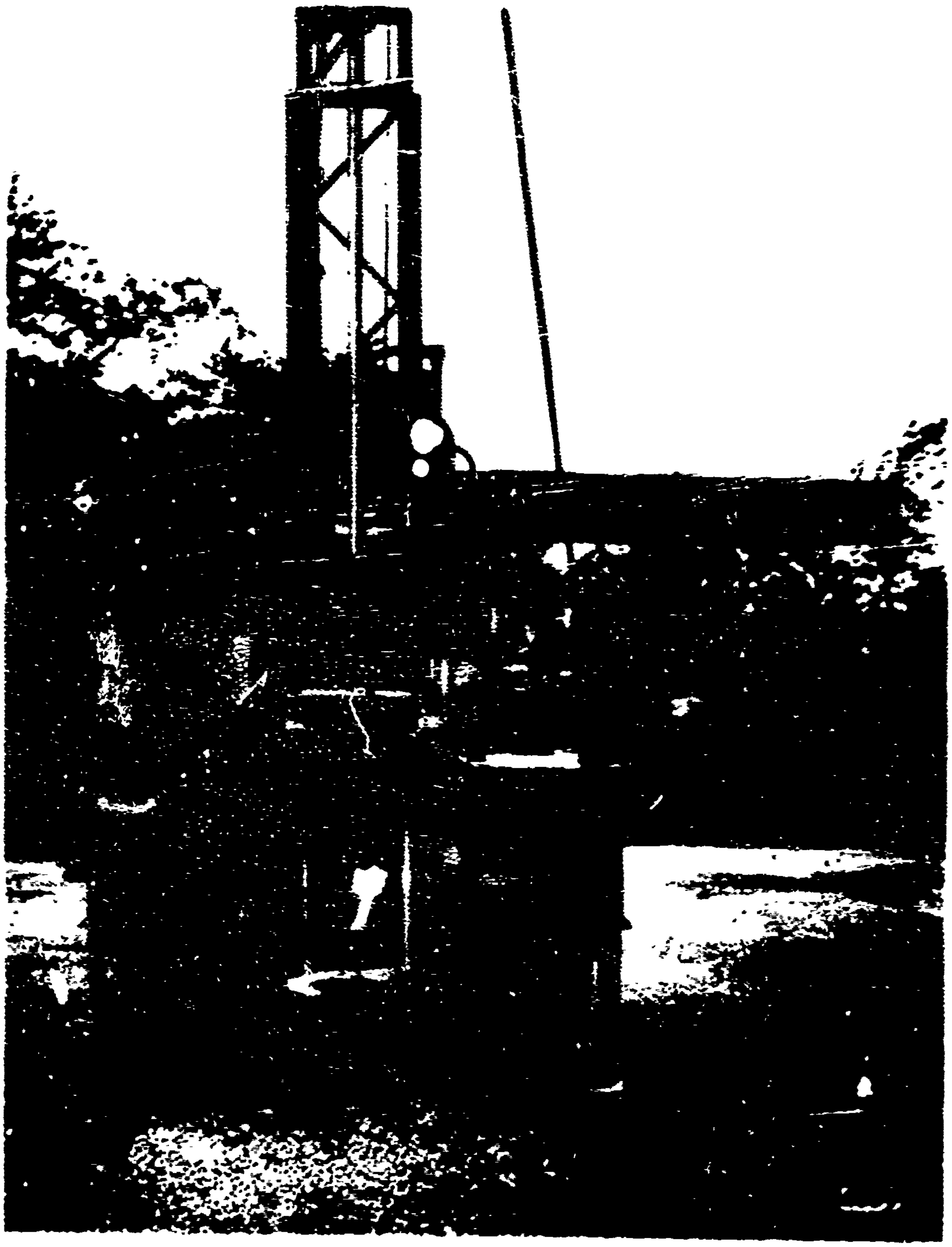


Figure 6. Tray in Full Right Position

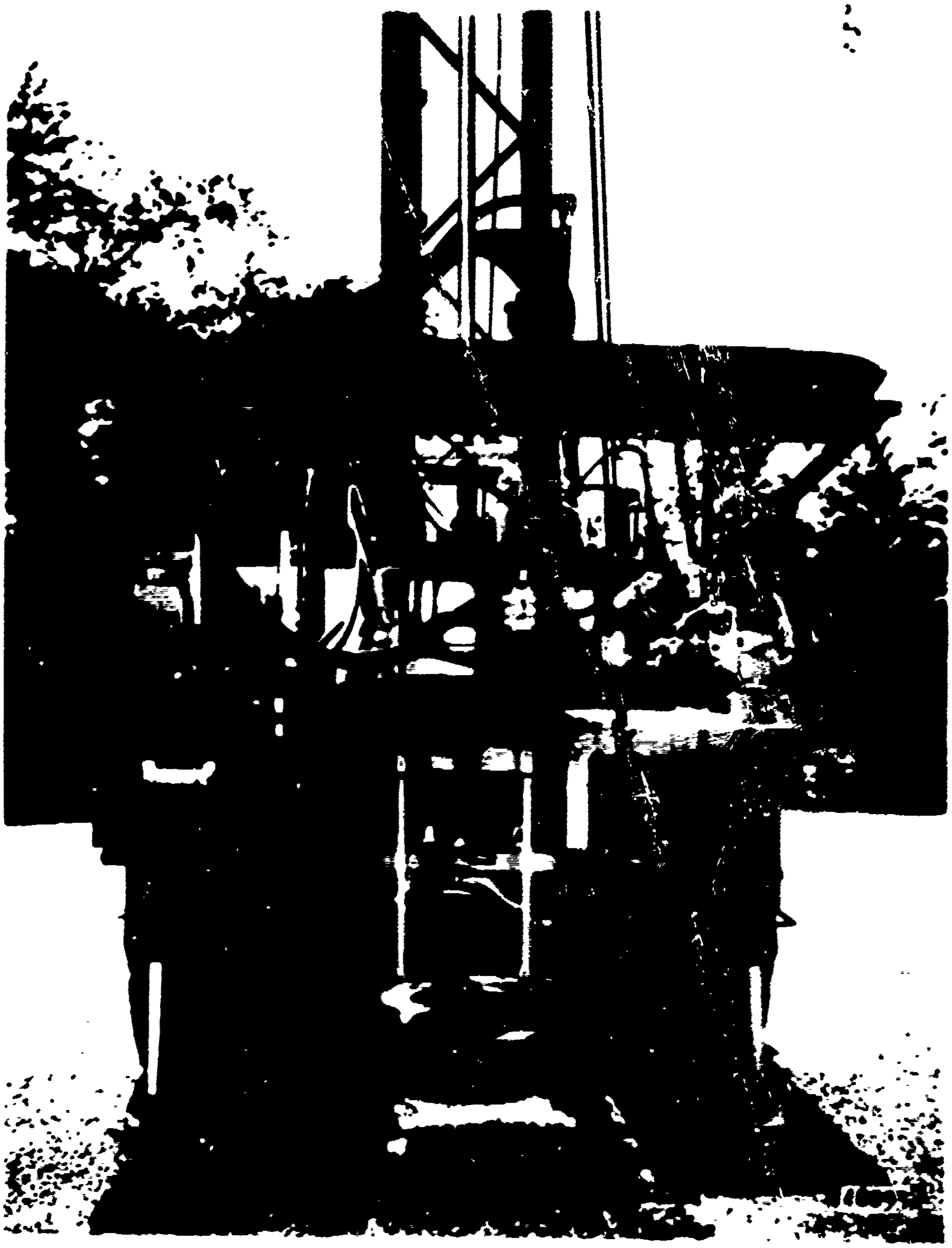


Figure 7. Tray in Traveling Position

The feeder was tested for all modes of operation and functioned in a completely satisfactory manner. The indexing drive is stroked by a push button from a remote position. The feeder was operated as fast as 120 strokes per minute during tests, but in drilling operations a rate of 30 strokes per minute is expected to be near the maximum practical rate.

C. Explosive Capsule Development

The concept of a multi-jet, all-plastic, shaped charge capsule emerged from the research effort. Extensive testing performed during those programs indicated that the multi-jet shaped charge concept was effective in focusing a major part of the explosive energy on the face of the rock and that satisfactory drilling efficiency could be expected. Tests also indicated that holes of the desired diameter could be produced with capsules of convenient size.

Because the capsules were constantly being varied in size and configuration, most of the testing on the research programs was static testing performed with only the explosive assembly portion of the capsule. These capsules were manually positioned in the holes and individually exploded. However, one complete capsule was developed in a 2.50-inch diameter size that was equipped with a firing train and an out-of-line safety arrangement. Experience with this capsule indicated that the procedures envisioned for automatic feeding and functioning of the explosive capsules were sound. No efforts had been made to design a firing train and safety system for the larger size capsules; therefore, one of the important tasks of this program was to design and develop a firing train and safety system that was compatible with the feeder, and would provide a convenient safe method of handling.

An early decision was necessary on the diameter of the capsule. The research work had indicated that a 4-inch diameter capsule loaded with 160 grams of explosive would drill a hole of about 14-inch diameter in quality limestone and granite. It was also determined that a 5-inch diameter capsule containing 265 grains of explosive would expand the diameter of the hole to about 20-inches. The experiments also indicated that an intermix of 4- and 5 inch diameter capsules was effective in drilling a 20-inch diameter hole. An idea was conceived, however, but has not been tried experimentally, for obtaining a 20- to 24-inch diameter hole with a 4-inch capsule alone. This consists of arranging the nozzle or exit end of the drill stem so the capsules will impact the bottom of the borehole 4 to 5-inches off the center of the hole. The drill stem will be rotated slowly, and as drilling proceeds, a hole of 20 inch diameter or more should be generated. This prospect of obtaining a 20 inch diameter hole with a 4 inch diameter capsule plus the dimensional properties of commercially available drilling equipment led to a decision to design the feeder and capsule system around the 4 inch diameter capsule.

The Mobile Drill Company equips one of their standard drill rigs with a rotary drive that has an opening in the center that measures 4.625 inches in diameter. This equipment was selected for use, and the center hole was bushed with a sleeve having a 4.375-inch inside diameter. This sleeve functions as part of a rotary joint for the compressed air and provides a smooth passage for the capsules through the rotary drive. These dimendional constraints led to a decision to design a capsule with a 4.312-inch outside diameter.

Safety of the capsule during loading, handling, storage, and use was a matter that received a great deal of design attention and influenced several features of the capsule. Details of the capsule are illustrated in Figure 8. The configuration of the high explosive section, except for a small change in diameter was made nearly identical to the 4-inch capsules that had evolved from the previous research work. A skirt has been attached to the high explosive section to provide standoff. for the shaped charge and obtain a good length to diameter (L/D) ratio for stability in the feeder cups and during passage through the drill stem. Assembled atop the high explosive section is the firing train assembly that incorporates the safety provisions and provides additional L/D properties.

The firing train and safety provisions function in the following manner. A slider assembly is loaded with a M-55 stab detonator and booster. The M-55 detonator was chosen because of its availability and economy. It is widely used and, therefore, manufactured in very large quantities at a current cost of about eight cents per unit. The output of the detonator is insufficient to detonate the explosive charge directly; therefore, a small booster is employed in the firing train to produce the necessary energy. This will be a simple booster consisting of a thin aluminum cup filled with Petn or Lead Azide explosive. When the slider is installed in the capsule, these explosive elements are positioned out-of-line with the firing pin and held there by a cotter pin that is inserted with the end bent to prevent its backing out except under an appreciable force. This constitutes one of the safety features of the capsule. The firing pin is installed in the capsule as shown in Figure 8. Its movement is restrained by a spring that will prevent motion unless an acceleration of 2.00 g's or more is applied in an axial direction. Its motion is also prevented by a lock created by a ball held in engagement with a groove in the pin by a spring clip. When this spring clip is removed, the lock disappears. This is the second safety on the capsule. At assembly, both safety arrangements are installed and both must be removed for the capsule to become armed. The feeder and capsule have been arranged so that both safety devices are removed automatically when the capsule moves into position over the drill stem and begins its motion down the drill stem. The first action in the arming sequence is the removal of the spring clip that secures the lock on the firing pin. This clip is withdrawn as the capsule is moved into position over the drill stem. The cotter pin that has prevented motion of the slider containing the firing train is withdrawn by the motion of the

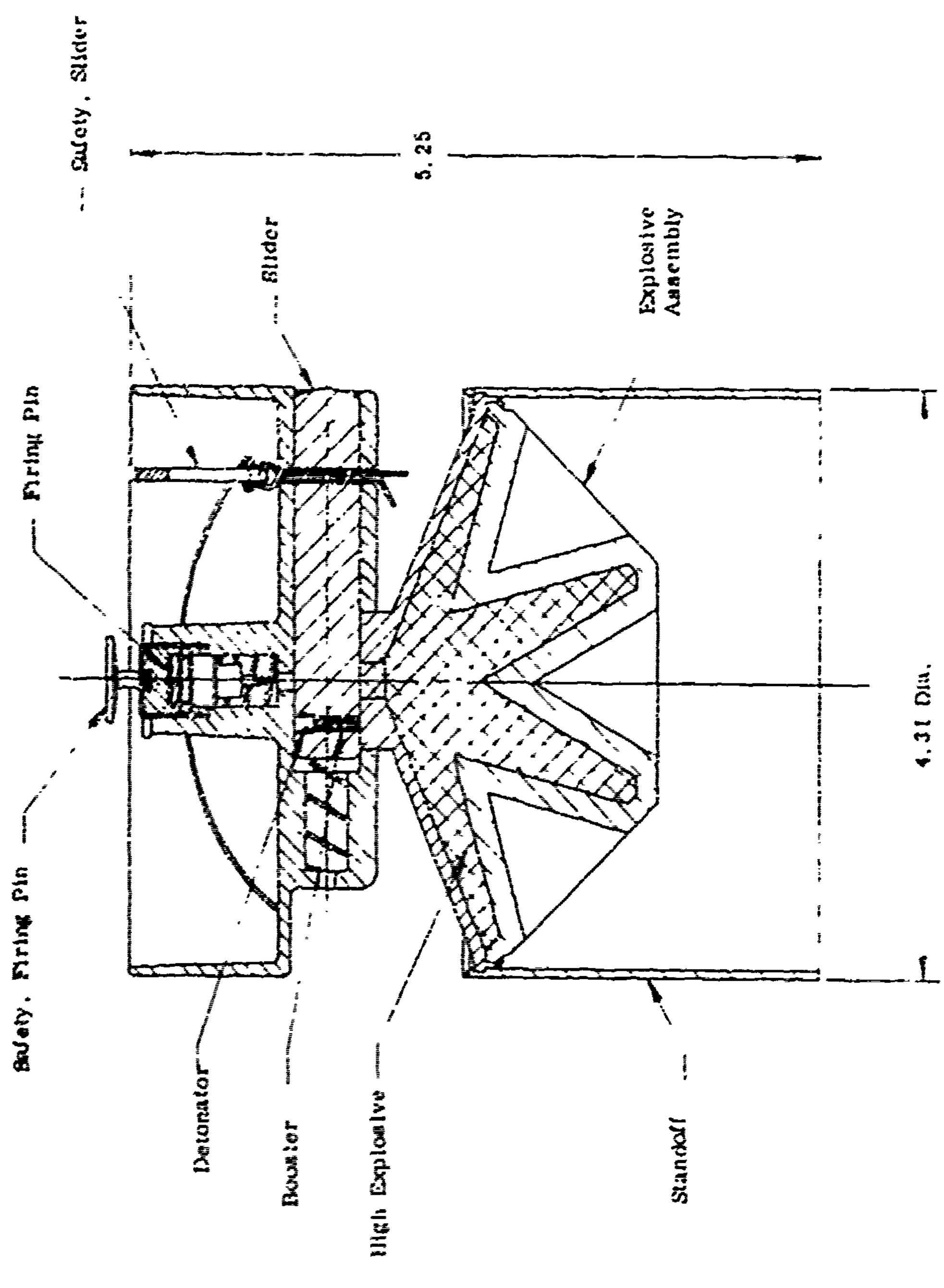


Figure 8. Configuration Of Explosive Capsule

capsule as it begins its travel down the drill stem. The capsule is still not armed, however, since the slider is prevented from moving because it is riding the bore or inside diameter of the drill stem. When the capsule exits from the drill stem, this restraint terminates, and a spring will move the slider sufficiently to position the firing train in line with the firing pin. The capsule is now armed, and when it strikes the bottom of the borehole, the firing pin will accelerate downward, strike the M-55 detonator, and explode the capsule.

A final safety feature is associated with the cotter pin. When it is withdrawn from the slider, it is retained on a wire that is secured to the capsule. If a capsule should become lodged in the drill stem, it must be removed. This is accomplished by lowering a hook that, with a little maneuvering, will hook the wire and the attached cotter pin. The capsule is then pulled to the top of the drill stem where either the cotter pin is installed in the slider or the firing pin is removed before withdrawing the capsule from the feeder cup. A view of an assembled capsule is shown in Figure 9.

The explosive capsule is an expendable item and, therefore, must be manufactured at an affordable cost if explosive drilling is to be economically attractive. This matter received considerable attention during design, and some tooling work was performed to check the efficiency of production processes.

The tooling studies were concerned with the plastic parts. A mold was made for the upper assembly which produced good parts in ABS (Acrylonitrile Butadiene Styrene) material, one of the more economical resins. This is a fairly complex part that would be expensive to fabricate by any other process.

The lower part or explosive housing presents special fabrication problems plus there are constraints on the choice of material. Views of this explosive assembly are presented in Figures 10 and 11. The following constraints are important factors in selecting the material: The capsule is loaded with explosive by a casting process and the temperature of the explosive is about 100°C, when it is poured into the capsule. The melt temperature of the plastic must be well above this temperature otherwise the capsule will melt or distort. In the thermoplastic group this limits the choice of materials considerably. Also, it has been assumed it would be beneficial to make the cone liners of a glass-filled plastic since glass is a material often used as a shaped charge liner. Some evidence was obtained during the research programs to support this assumption when the performance of shaped charges equipped with liners containing 45% and 60% were compared. The benefits of the higher glass content, however, were not pronounced. On this program, the material used was 612 nylon containing 60% glass by weight.

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Figure 9. View Of An Assembled Capsule

Figure 10. Top View Of Explosive Assembly

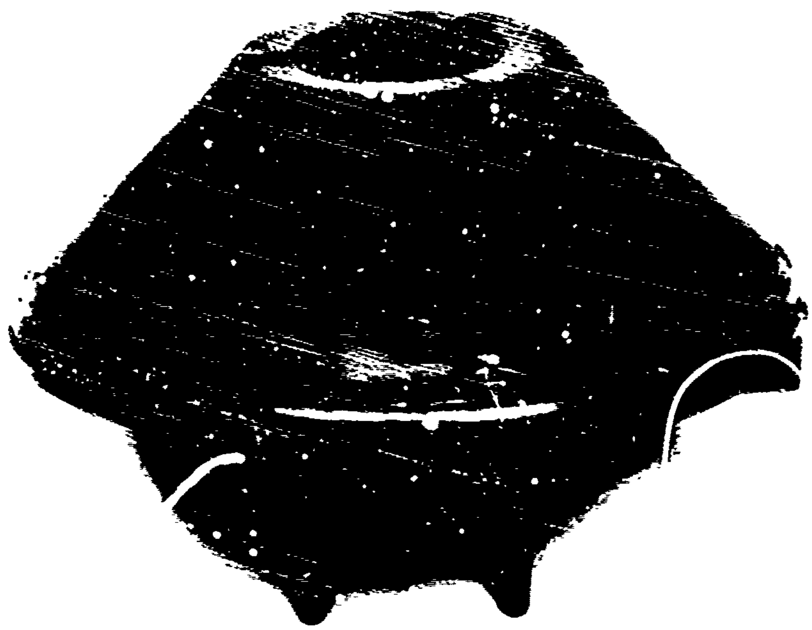

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Figure 11. Bottom View Of Explosive Assembly

This is a satisfactory material, but its current price in large quantities is $1.75 per pound and, therefore, is not an economical material. Molding of the lower part of this housing which contains the cone liners is a difficult problem. The geometry of the part is such that it cannot be molded in a single piece. After considerable study, a process was selected where this lower part was molded in thirds. Each third was identical and was easy to mold, but it is then necessary to join them to form the lower assembly. The lid or top molding is then attached to complete the explosive assembly housing. Joining the parts is accomplished by applying heat along the seams. This melts the resin momentarily, and when it cools, the seams are closed and an integral assembly results. This process produced good parts, but the tooling was elementary and considerable labor was required in the assembly operation. Good tooling is needed to reduce the labor and assure uniform quality.

The design of the remaining parts of the capsule appear to be satisfactory for quantity production. The parts can be fabricated by plastic molding,or on a screw machine, or by stamping all of which are standard, high-production, economical labor saving processes.

Several innovations were designed into the plastic parts to reduce assembly time to a minimum. One of these innovations can be seen in Figure 9. The two projecting prongs are inserted into holes in the upper assembly molding. Heat is applied momentarily to the ends of these prongs and a permanent assembly is accomplished in a matter of a few seconds. Other innovations proved equally successful and additional use of innovative techniques should be developed.

Explosive loading of the capsule presented a problem that required the assistance of a firm experienced in this type of activity. On the research program, explosive loading had been accomplished by manual packing of the capsules with C-4 explosive. This required an appreciable amount of labor; therefore, development of a more economical process was necessary. The services of Trojan Powder in Allentown, Pennsylvania were obtained to conduct experiments in explosive loading. Design of the capsule was modified to include a filler spout in the cover of the explosive housing assembly. This spout can be seen in Figure 10. Using this spout, Trojan Powder experienced no problems in loading the capsules with pentolite. Pentolite was used because Trojan is a manufacturer of this material and preferred working with it rather than composition "B". Either material can be cast and will be a satisfactory explosive material for the capsule. The weight of the capsules was closely monitored during the loading experiments to detect whether or not voids would develop. Weights were uniform and reached the expected values indicating that the cavity was filling well. This quality was confirmed on two of the capsules by opening them and examining them for voids. No voids were found.

DISCUSSIONS

One of the technical problems faced during design of the feeder was determination of the load factors to use to design the structure. The principal consideration was the shock type loads generated by the explosion. The explosions occur down the hole and parallel situations could not be found in the literature to serve as a guide as to what these loads might be or how they might be estimated. Faced with this situation, a conservative approach was taken and the impulse on a surface near the explosion the size of the borehole was computed and applied to the drill stem. The mass of the parts attached to the drill stem was estimated and the acceleration that the impulse would produce was computed. The computed value was 45 g's and this became the determining factor in designing the structure of the feeder. Faced with this load factor, it was necessary to limit the weight of the feeder as much as possible. This led to the selection of aluminum for the material in the tray and the cups. The bottom of the tray was covered with nylatron sheet to minimize friction and curtail wear. Other wear surfaces were protected in a like manner.

Plans had always included the use of an indexing drive that would be pneumatically powered, but a decision was necessary regarding the operating pressure. It is envisioned that the compressors used to supply air for spoils removal will probably be axial type compessors used in engine starters. These compressors usually supply air at around 40 psig. It is probable, therefore, that this will become the operating pressure for the pneumatic system so an indexing mechanism was selected that would be compatible with this supply. This resulted in the selection of a larger mechanism than would ordinarily be employed, but space was found for its installation and the system functions very nicely at an air pressure of 40 psig. On this program the feeder was operated on air taken from the receiver that supplies compressed air to the brakes on the truck. The capacity of this supply is adequate and its pressure is 100 psig. The pressure was reduced for the tests. This is an alternate arrangement that works quite well and could be used in the final system if desired. All technical problems associated with the feeder were resolved and the system functioned in tests in a satisfactory manner. The tests indicated that the system will be capable of feeding the explosive capsules at any desired rate and will fulfill the need for equipment necessary to conduct meaningful experiments in explosive drilling.

The safety features developed for the capsule functioned well during tests. The out-of-line safety feature for the firing train and the bore riding arrangement to maintain an unarmed status until the capsule exits from the drill stem has always been part of the envisioned safety provisions. A need was recognized for a second independent safety provision and locking the firing pin appears to have fulfilled this goal satisfactorily. The fact that both safety devices can remain intact in all modes of handling, and personnel are at a remote safe distance when they are removed, is considered an important safety feature.

The ability to fabricate the explosive capsules at a reasonable cost is an important consideration, and for the most part, the designs developed during the program should satisfy this goal. All of the capsule parts, with the exception of the explosive housing, can be fabricated of economical materials by standard mass production techniques. These are the essential ingredients for economical manufacture. The assembly process is also simple and capable of being accomplished with reasonable effort. Explosive loading can be performed by an established production process, and the design appears to be adequate from this standpoint.

Studies to determine whether alternate materials and production methods can be employed to fabricate the explosive housing might be justified. As previously pointed out, design of this part is subject to a number of constraints such as compatibility with the 100°C temperature of the molten explosive, the desire for a high glass content in the liners, and the geometry and arrangement of the liners. This housing, including the cover, weighs 140 grams, and at $1.75 per pound for large quantity requirements, the material cost of glass filled nylon is 54 cents. The prospects for locating a satisfactory alternate material are fairly good. For example, on the basis of published data, it appears that heat resistant, glass filled ABS material might satisfy the temperature requirement. This material can be obtained at about half the cost of nylon, making the projected cost of the material 25 to 30 cents per part. Studies should also be made to determine whether a more economical fabrication process than the one currently employed can be developed. It may well be that the current process, in large quantity production, will be quite economical. The molding method is simple and as economical as can be obtained. Three parts are required per assembly since it is molded in thirds, but molding costs can be controlled by using multi cavity molds. Assembly of the parts in the current program required considerable time, but this operation, also, would become inexpensive with the development of proper fixtures and tools. Because of the geometry of the lower part, no way is envisioned for its fabrication as a single molding. This means that an assembly operation cannot be avoided, and economy of fabrication will depend largely upon the efficiency at which assembly can be performed.

All the parts in the capsule can be fabricated on a screw machine, or by stamping, or by molding. All these fabrication methods are recognized, low labor, high quantity, low cost processes. A good indicator, therefore, of large quantity costs is the cost of the materials. The following is an estimate of material costs for the capsule.

ITEM	WEIGHT lbs.	MATERIAL COST $/lb.	UNIT COST $
Explosive Housing	.308	0.85	0.2621
Explosive	.374	1.50	0.5610
Upper Molding	.207	0.50	0.1035
Slider	.021	0.85	0.0018
Springs (2)	.002	-	.0600
Detonator - M55	-	-	.0800
Booster	-	-	.1500
Standoff Skirt	.079	0.50	.0396
Firing Pin	.014	0.30	.0042
Safety-Slider	.0066	2.00	.0132
Spring - F.P. Safety	.0017	2.00	0.0034
Knob - F.P. Safety	.0067	.50	0.0033
Cap	.0036	.50	0.0018
	1.0236		$1.2839

The $1.28 figure is the cost for material with no allowance for scrappage or operating overheads and profit. If a 20% allowance is made for material loss during fabrication and 45% is added for overhead and profit, the cost of materials becomes $2.23 per capsule.

CONCLUSIONS

The following conclusions are drawn from the experience and findings of this program.

- Tests of the feeder system indicated satisfactory performance in all modes of operation, and the system appears to be ready and suited for use in conducting experiments in explosive drilling.

- Feeder tests under the shock load conditions that will be experienced during drilling operations were not conducted. These tests would have required extensive preparations and, therefore, were not included in the scope of this program. Performance of the feeder and the drill rig under these conditions will be determined when experiments in explosive drilling begin.

- Experiments indicate that the capsules can be loaded satisfactorily with pentolite or composition "B" explosive by a casting process. This is a standard production loading method, therefore, the design appears to be satisfactory from this standpoint.

- The two independent methods of inhibiting arming of the capsule performed satisfactorily in tests. The safety provisions developed for handling and use of the capsule appear to be adequate for use in the envisioned explosive drilling process.

- Projected costs for capsule materials and review of the designs from a production engineering standpoint indicate that the capsule can be produced at a reasonable cost in large quantity production. The availability of an economical capsule, however, is a vital economic consideration, and continued monitoring of designs, materials and fabrication techniques to further reduce capsule costs is justified.

RECOMMENDATIONS

The results of this program lead to the following recommendations regarding future investigation of this explosive drilling process.

It was demonstrated that both the feeder and the capsules perform in an acceptable and expected manner, and are suitable for use in planning further development of this explosive drilling concept. It is recommended, therefore, that the following plans be considered.

a. Equipment such as drill stem, augers, casing, and miscellaneous connectors and adapters should be designed, fabricated, and procured to equip the drill rig for conducting experiments in explosive drilling.

b. A quantity of explosive capsules sufficient to conduct a series of drilling experiments should be fabricated.

c. Plans should be made to obtain the compressors needed to supply compressed air for spoils removal. These may be rented or procured.

d. Experiments in explosive drilling should be planned and conducted to resolve technical problems and examine the effectiveness and efficiency of this explosive drilling technique.

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